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EVALUATION OF REFERENCE EVAPOTRANSPIRATION ESTIMATION METHODS IN NELLORE REGION

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ABSTRACT

In the present study, nine empirical methods for calculating daily reference evapo transpiration (ET_0) namely, Blaney-Criddle, Jensen-Haise and Hargreaves (temperature based), Priestley-Taylor, Radiation and Makkink (radiation based), Modified Penman (physically based), Pan Evaporation and Christiansen (pan evaporation based) methods have been evaluated with respect to FAO-56 Penman-Monteith(PM) method for estimating daily ET_0 in the semi-arid Nellore region of Andhra Pradesh, India. Data was collected from the India Meteorological Department (IMD), Pune. The evaluation is based on performance criteria namely, Root Mean Square Error (RMSE), Coefficient of Determination (R^2) and Efficiency Coefficient (EC). The relationships between PM method and the other methods were developed to obtain daily ET_0 estimates comparable with PM method. The ET_0 equations were then recalibrated with respect to PM method for improving their daily ET_0 estimation capability in the region selected for the present study. The recalibrated Modified Penman and Blaney-Criddle methods showed satisfactory performance in the daily ET_0 estimation. However, the recalibrated Blaney-Criddle method may be adopted because of its simpler data requirements with reasonable degree of accuracy.

KEYWORDS: Reference Evapotranspiration, Recalibration, Performance Evaluation

INTRODUCTION

A reliable estimation of Evapotranspiration (ET) is of critical importance in irrigation system design, crop yield simulation and water resources planning and management. Field measurement of evapotranspiration is rarely available and actual crop evapotranspiration (ET_c) is usually calculated from reference evapotranspiration (ET_0) using the crop factor method, which consists of multiplying ET_0 with crop coefficients (K_c) to obtain ET_c (i.e., $ET_c = ET_0 \times K_c$). Several reports on the estimation of K_c are available.Allen et al. (1998)[2] and Jensen et al. (1990)[5]have reported crop coefficients for many crops. These values are commonly used in places where the local data is not available.

It is desirable to have a method that estimates reasonably the reference Evapotranspiration (ET_0). According to the Food and Agricultural Organization (FAO), FAO-56 Penman-Monteith (PM) method, that requires numerous climatic parameters, achieves better agreement with the lysimeter ET_0 measurements compared to all other known methods. However, under limited climatic data availability conditions, the simple empirical methods yielding results comparable with PM ET_0 may be selected at regional level for reasonable estimation of ET_0.

Irmak et al.(2003)[4], Berengena and Gavilan(2005)[3], Alkaeed et al.(2006)[1], Suleiman and Hoogenboom (2007)[8], Trajkovic and Stojnic (2008)[9] have evaluated, compared and tested the applicability of various ET_0 equations for different regions.

The present study reports the performance evaluation of commonly used nine ET_0 estimation methods based on their accuracy of estimation and these methods are recalibrated with PM method for Nellore region of Andhra Pradesh.

MATERIALS AND METHODS

Nellore region, located in Nellore district of Andhra Pradesh, India, with global coordinates of $14^0\,22'$ N latitude and $79^0\,59'$ E longitudes, has been chosen as the study area. Daily meteorological data at the region for the period 1983-2003 was collected from India Meteorological Department (IMD), Pune. A part of the data (1983-1997) was used for developing recalibrated equations, while the rest of the data (1998-2003) was used to verify the performance of the recalibrated equations. The details of the methods selected for the present study are presented in Table 1.

Table 1: Details of Reference Evapotranspiration Estimation Methods

Method	Equation	Input Data	
		Primary	Secondary
Temperature based 1. FAO-24Blaney-Criddle(BC) method	$ET_0 = a + b\,[p\,(0.46T + 8.13)]$ Where $a = 0.0043\,(RH_{min}) - n/N - 1.41$ $b = 0.82 - 0.0041\,(RH_{min}) + 1.07\,(n/N) + 0.066\,(u_d) - 0.006\,(RH_{min})\,(n/N) - 0.0006\,(RH_{min})\,(u_d)$	T_{max}, T_{min}	RH_{min}, n, u_d, u_d/u_n
2. Jensen-Haise (JH) method	$ET_0 = R_s\,(0.025\,T_{mean} + 0.08)$	T_{max}, T_{min}, n	—
3. FAO-56 Hargreaves (HR) method	$ET_0 = 0.0023\,R_a\,(T_{mean} + 17.8) \times (TD)^{0.5}$	T_{max}, T_{min}, n	—
Radiation based 1. Priestley-Taylor (PT) method	$ET_0 = 1.26\dfrac{\Delta}{\Delta + \gamma}(R_n - G)$	T_{max}, T_{min}, n	---
2. FAO-24 Radiation (RA) method	$ET_0 = c\,(W R_s)$ Where $c = 1.066 - 0.00128\,RH_{mean} + 0.045\,u_d - 0.0002\,RH_{mean}u_d + 0.0000315\,(RH_{mean})^2 - 0.00103\,(u_d)^2$	T_{max}, T_{min}, n	RH_{max}, RH_{min}, u_d, u_d/u_n
3. Makkink (MK) Method	$ET_0 = 0.65\dfrac{\Delta}{\Delta + \gamma}R_s$	T_{max}, T_{min}, n	---
Physically based 1. FAO-24 Modified-Penman (MP) method	$ET_0 = C \times \left[\dfrac{\Delta}{\Delta + \gamma}R_n + \dfrac{\gamma}{\Delta + \gamma}(0.27)(1.0 + 0.01U_2)(e_s - e_a)\right]$ Where $C = 0.68 + 0.0028\,(RH_{max}) + 0.018\,(R_s) - 0.068\,(u_d) + 0.013\,(u_d/u_n) + 0.0097\,(u_d)(u_d/u_n) + 0.000043\,(RH_{max})\,(R_s)\,(u_d)$	T_{max}, T_{min}, RH_{max}, RH_{min}, n	u_d, u_d/u_n
2. FAO-56 Penman-Monteith (PM) method	$ET_0 = \dfrac{0.408\,\Delta'(R_n' - G') + \gamma'\dfrac{900}{T_{mean} + 273}u_2(e_s' - e_a')}{\Delta' + \gamma'(1 + 0.34u_2)}$	T_{max}, T_{min}, RH_{max}, RH_{min}, u_2, n	---
Pan Evaporation based 1. FAO-56 Pan Evaporation (PE) method	$ET_0 = K_p\;E_{pan}$ where $K_p = 0.108 - 0.0286\,u_2 + 0.0422\,\ln(FET) + 0.1434\,\ln(RH_{mean}) - 0.000631\,[\ln(FET)]^2\,\ln(RH_{mean})$	E_{pan}	FET, RH_{max}, RH_{min}, u_2
2. Christiansen (CS) method	$ET_0 = 0.473\,R_a\,C_T\,C_W\,C_H\,C_S\,C_E\,C_M$ where $C_T = 0.393 + 0.5592\,(T/T_o) + 0.04756\,(T/T_o)^2$ $C_W = 0.708 + 0.3276\,(U_2/U_{2o}) - 0.036\,(U_2/U_{2o})^2$ $C_H = 1.25 - 0.212(RH/RH_o) - 0.038(RH/RH_o)^2$ $C_S = 0.542 + 0.64(s_p/s_{po}) - 0.4992(s_p/s_{po})^2 + 0.3174(s_p/s_{po})^3$	—	T_{max}, T_{min}, u_2, RH_{max}, RH_{min}, n, E

PERFORMANCE EVALUATION CRITERIA

The performance evaluation criteria used in the present study are the coefficient of determination (R^2), the root mean square error (RMSE), systematic RMSE, unsystematic RMSE and the efficiency coefficient (EC).

Coefficient of Determination (R^2)

It is the square of the correlation coefficient (R) and the correlation coefficient is expressed as

$$R = \frac{\sum_{i=1}^{n} (o_i - \overline{o})(p_i - \overline{p})}{\left[\sum_{i=1}^{n} (o_i - \overline{o})^2 \sum_{i=1}^{n} (p_i - \overline{p})^2\right]^{1/2}}$$

Where O and P are observed and estimated values, $\overline{O}$ and $\overline{P}$ are the means of observed and estimated values and n is the number of observations. It measures the degree of association between the observed and estimated values and indicates the relative assessment of the model performance in dimensionless measure.

Root Mean Square Error (RMSE)

It yields the residual error in terms of the mean square error and is expressed as (Yu et al., 1994)[10]

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (p_i - o_i)^2}{n}}$$

Systematic RMSE ($RMSE_s$)

It measures the room available for local adjustment. It is expressed as

$$RMSE_s = \sqrt{\frac{\sum_{i=1}^{n} (\hat{p}_i - o_i)^2}{n}}$$

Where $\hat{p}_i = a + bo_i$, a and b are the liner regression coefficients

Unsystematic RMSE ($RMSE_u$)

It shows the noise level in the model and is a measure of scatter about the regression line and potential accuracy. It is expressed as

$$RMSE_u = \sqrt{\frac{\sum_{i=1}^{n} (p_i - \hat{p}_i)^2}{n}}$$

Efficiency Coefficient (EC)

It is used to assess the performance of different models (Nash and Sutcliffe, 1970)[7]. It is a better choice than RMSE statistic when the calibration and verification periods have different lengths (Liang et al., 1994)[6]. It measures directly the ability of the model to reproduce the observed values and is expressed as

$$EC = 1 - \frac{\sum_{i=1}^{n} (o_i - p_i)^2}{\sum_{i=1}^{n} (o_i - \overline{o})^2}$$

A value OF EC of 90% generally indicates a very satisfactory model performance while a value in the range of 80-90% indicates a fairly good model. Values of EC in the range 60-80% would indicate an unsatisfactory model fit.

RESULTS AND DISCUSSIONS

ET_0 was estimated using the climatic data for different methods with original values of empirical coefficients. The mean daily values were compared with those estimated by PM method. The percentage deviations with reference to PM method are shown in Table 2. The positive deviation represents overestimation and negative deviation indicates underestimation of ET_0 values. It may be observed that the percentage deviation between PM method and other methods varied between –14.9% and 55.3%. RA method estimated ET_0 with largest deviation followed by JH method and, PT, CS, HR and BC methods with minimum deviation. The performance indicators of the methods with original coefficients are presented in Table 3. The relatively more unsystematic RMSE components with the ET_0 estimation methods except MP and BC methods indicate more noise level in the methods and scatter about the regression line.

The temperature, radiation, physically and pan evaporation based methods selected for the present study were recalibrated with respect to PM method as presented in Table 4. The performance indicators of these empirical models with original and recalibrated coefficients in the estimation of ET_0 are given in Table 5. The improved R^2, EC and reduced RMSE (Table 5) indicate the closeness of estimated daily ET_0 values and thereby reflect the appropriateness of recalibration. An improvement in the performance of ET_0 estimation methods with recalibrated coefficients over these methods with original coefficients, in general, has been observed (Table 5). A significant improvement has been found in case of recalibrated MP and BC methods. However, out of these methods, recalibrated BC method may be adopted in the reasonable daily ET_0 estimation in the region because of simpler data requirements. The scatter plots as shown in Figure 1 & 2 also depict similar observations.

Table 2: Percentage Deviations in the Estimated Mean Daily Reference Evapotranspiration with Original Coefficients

Method	PM	BC	JH	HR	PT	RA	MK	MP	PE	CS
$ET_{0\,s}$(mm)	4.7	4.5	6.3	4.6	4.8	7.3	4	6.1	4.2	4.8
Percentage Deviation		-4.3	34.0	-2.1	2.1	55.3	-14.9	29.8	-10.6	2.1

Table 3: Performance Indicators of Various Methods with Original Coefficients against PMM

Method	Slope(m)	Intercept(c)	R^2	RMSE (mm)	RMSE$_s$ (mm)	RMSE$_u$ (mm)	EC (%)
BC	0.8919	0.6349	0.9099	0.42	0.13	0.40	90.99
JH	0.6443	0.6299	0.7125	0.76	0.41	0.64	71.25
HR	0.9589	0.2224	0.5899	0.90	0.58	0.69	58.99
PT	0.9227	0.2826	0.6301	0.86	0.52	0.68	63.01
RA	0.5547	0.6238	0.5738	0.92	0.60	0.70	57.38
MK	1.0149	0.6566	0.5740	0.92	0.60	0.70	57.40
MP	0.7479	0.1487	0.9656	0.26	0.05	0.26	96.56
PE	0.5523	2.3673	0.3780	1.11	0.88	0.68	37.80
CS	0.8921	0.3792	0.8756	0.50	0.18	0.47	87.56

Table 4: ET_0 Estimation Methods with Original and Recalibrated Coefficients

Method	Original Equation	Recalibrated Equation
BC	$ET_0 = a + b\,[p\,(0.46T + 8.13)]$ where $a = 0.0043\,(RH_{min}) - n/N - 1.41$ $b = 0.82 - 0.0041\,(RH_{min}) + 1.07\,(n/N) + 0.066\,(u_d) - 0.006\,(RH_{min})\,(n/N) - 0.0006\,(RH_{min})\,(u_d)$	$ET_0 = a + b\,[p\,(0.46T + 8.13)]$ where $a = -0.0447\,(RH_{min}) - 3.14\,(n/N) + 2.36$ $b = 0.013 + 0.0072\,(RH_{min}) + 0.84\,(n/N) + 0.196\,(u_d) + 0.003\,(RH_{min})\,(n/N) - 0.0023\,(RH_{min})\,(u_d)$
JH	$ET_0 = R_s\,(0.025\,T + 0.08)$	$ET_0 = R_s\,(0.0296\,T - 0.27)$
HR	$ET_0 = 0.0023\,R_a\,(T + 17.8) \times (TD)^{0.5}$	$ET_0 = 0.0025\,R_a\,(T + 13.6) \times (TD)^{0.5}$
PT	$ET_0 = 1.26\,\frac{\Delta}{\Delta+\gamma}(R_n - G)$	$ET_0 = 1.22\,\frac{\Delta}{\Delta+\gamma}(R_n - G)$
RA	$ET_0 = c\,(W.R_s)$ where $c = 1.066 - 0.00128\,RH + 0.045\,u_d - 0.0002\,RH\,u_d + 0.0000315\,(RH)^2 - 0.00103\,(u_d)^2$	$ET_0 = c\,(W.R_s)$ where $c = 0.918 - 0.00773\,RH + 0.321\,u_d - 0.0035\,RH\,u_d + 0.0000496\,(RH)^2 + 0.00107\,(u_d)^2$
MK	$ET_0 = 0.65\,\frac{\Delta}{\Delta+\gamma}R_s$	$ET_0 = 0.75\,\frac{\Delta}{\Delta+\gamma}R_s$
MP	$ET_0 = C$ $\left[\frac{\Delta}{\Delta+\gamma}R_n + \frac{\gamma}{\Delta+\gamma}(0.27)(1.0+0.01U_2)(e_s - e_a)\right]$ where $C = 0.68 + 0.0028\,(RH_{max}) + 0.018\,(R_s) - 0.068\,(u_d) + 0.013\,(u_d / u_n) + 0.0097\,(u_d)(u_d/u_n) + 0.000043\,(RH_{max})\,(R_s)\,(u_d)$	$ET_0 = C$ $\left[\frac{\Delta}{\Delta+\gamma}R_n + \frac{\gamma}{\Delta+\gamma}(0.27)(1.0+0.01U_2)(e_s - e_a)\right]$ Where $C = 0.60 + 0.0014\,(RH_{max}) + 0.012\,(R_s) - 0.009\,(u_d) + 0.013\,(u_d / u_n) + 0.0097\,(u_d)(u_d/u_n) - 0.000039\,(RH_{max})\,(R_s)\,(u_d)$
PE	$ET_0 = K_p\;E_{pan}$ where $K_p = 0.108 - 0.0286\,u_2 + 0.0422\,\ln(FET) + 0.1434\,\ln(RH) - 0.000631[\ln(FET)]^2\,\ln(RH)$	$ET_0 = K_p\;E_{pan}$ where $K_p = -1.402 + 0.1123\,u_2 + 0.0422\,\ln(FET) + 0.8075\,\ln(RH) - 0.000631[\ln(FET)]^2\,\ln(RH)$
CS	$ET_0 = 0.473\,R_a\,C_T\,C_W\,C_H\,C_S\,C_E\,C_M$ where $C_T = 0.393 + 0.02796\,T + 0.0001189\,(T)^2$ $C_W = 0.708 + 0.2144\,(u_2) - 0.01542\,(u_2)^2$ $C_H = 1.25 - 0.00369\,RH - 6.1\times10^{-11}\,(RH)^5$ $C_S = 0.542 + 0.80\,s_r - 0.78\,(s_r)^2 + 0.62\,(s_r)^3$ $C_E = 0.970 + 0.0000984\,E$ C_M = ranges from 0.9 to 1.1depending on the latitude	$ET_0 = 2.0\,R_a\,C_T\,C_W\,C_H\,C_S\,C_E\,C_M$ where $C_T = 1.07 - 0.06729\,T + 0.001366\,(T)^2$ $C_W = 0.798 + 0.003488\,W - 0.0000046\,(W)^2$ $C_H = 1.01 - 0.00647\,RH - 53.9\times10^{-11}\,(RH)^5$ $C_S = 0.661 + 0.39\,s_r + 0.95\,(s_r)^2 - 0.99\,(s_r)^3$ $C_E = 0.970 + 0.0000984\,E$ C_M = ranges from 0.9 to 1.1depending on the Latitude

Table 5: Performance Evaluation of ET_0 Estimation Methods with Original and Recalibrated Coefficients against PM Method

Method	Slope (m)			Intercept (c)			R^2			RMSE (mm)			EC (%)		
	Original	Recalibrated		Original	Recalibrated		Original	Recalibrated		Original	Recalibrated		Original	Recalibrated	
		Training	Testing		Training	Testing		Training	Testing		Training	Testing		Training	Testing
BC	0.8919	0.9997	1.0022	0.6349	-0.0010	-0.0453	0.9099	0.9797	0.9859	0.42	0.19	0.19	90.99	97.97	98.59
JH	0.6443	0.7839	0.8868	0.6299	1.0791	0.6193	0.7125	0.7432	0.8602	0.76	0.68	0.59	71.25	74.32	86.02
HR	0.9589	0.8758	1.0052	0.2224	0.6037	0.2251	0.5899	0.5491	0.5477	0.90	0.90	1.07	58.99	54.91	54.77
PT	0.9227	0.8785	1.1408	0.2826	0.5864	-0.4960	0.6301	0.5917	0.7329	0.86	0.85	0.82	63.01	59.17	73.29
RA	0.5547	0.7455	0.7105	0.6238	1.0649	1.1385	0.5738	0.9019	0.9524	0.92	0.42	0.35	57.38	90.19	95.24
MK	1.0149	0.9317	1.0712	0.6566	0.9852	-0.1759	0.5740	0.5219	0.7027	0.92	0.92	0.87	57.40	52.19	70.27
MP	0.7479	1.0098	1.0135	0.1487	-0.0413	-0.0756	0.9656	0.9947	0.9958	0.26	0.10	0.10	96.56	99.47	99.58
PE	0.5523	0.4796	0.7394	2.3673	2.2255	1.7291	0.3780	0.3916	0.5929	1.11	1.04	1.01	37.80	39.16	59.29
CS	0.8921	0.7105	0.6654	0.3792	1.4923	1.5999	0.8756	0.8705	0.8981	0.50	0.48	0.51	87.56	87.05	89.81

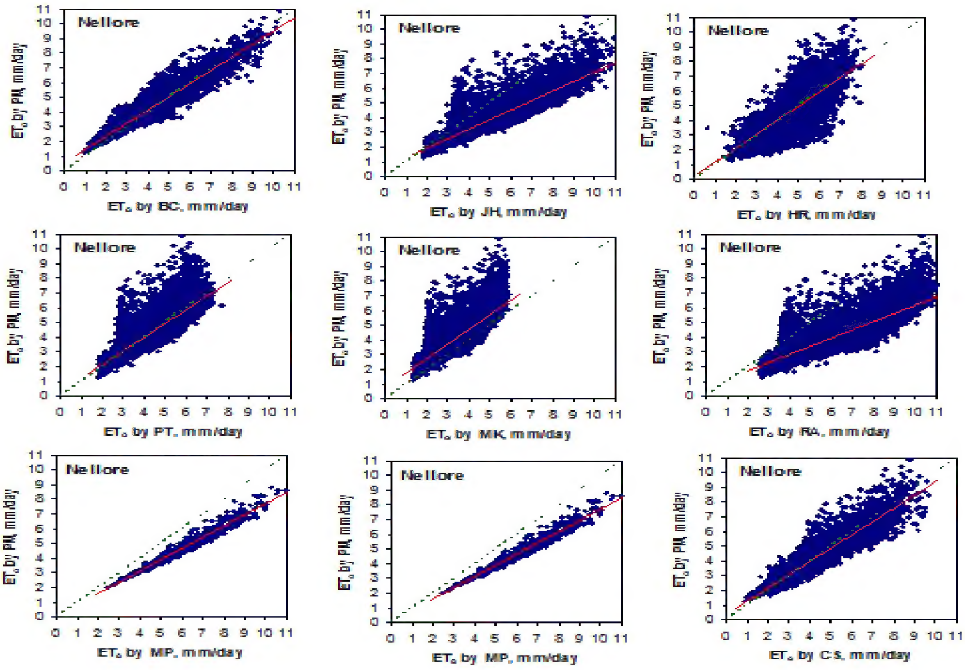

Figure 1: Scatter Plots of Daily ET_0 Estimated by Various Methods with Original Coefficients against ET_0 Estimated Using PM Method

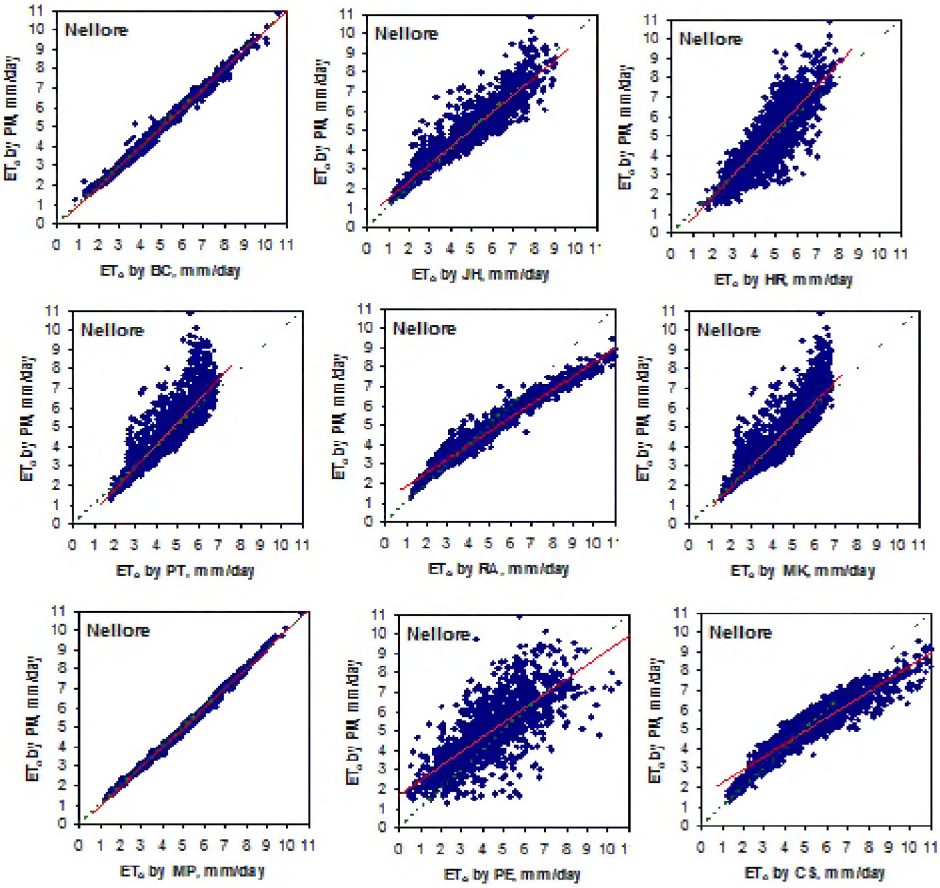

Figure 2: Scatter Plots of Daily ET_0 Estimated by Various Methods with Recalibrated Coefficients against ET_0 Estimated using PM Method during Testing Period

CONCLUSIONS

The Blaney-Criddle, Jensen-Haise and Hargreaves (temperature based), Priestley-Taylor, Radiation and Makkink (radiation based), Modified Penman (physically based), Pan Evaporation and Christiansen (pan evaporation based) reference evapotranspiration (ET_0) methods have been recalibrated with respect toFAO-56 Penman-Monteith method and their performance in the daily ET_0estimation in the Nellore region of Andhra Pradesh has been evaluated. All these ET_0 estimation methods, in general, showed an improved performance with recalibrated coefficients. But, the recalibrated Modified Penman method and recalibrated Blaney-Criddle method performed well in the daily ET_0 estimation. However, recalibrated Blaney-Criddle method may be applied for the reasonable estimation of daily ET_0 in the region because of simpler data requirements.

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